# Sports Injuries and Space Injuries: Prevention and Treatment

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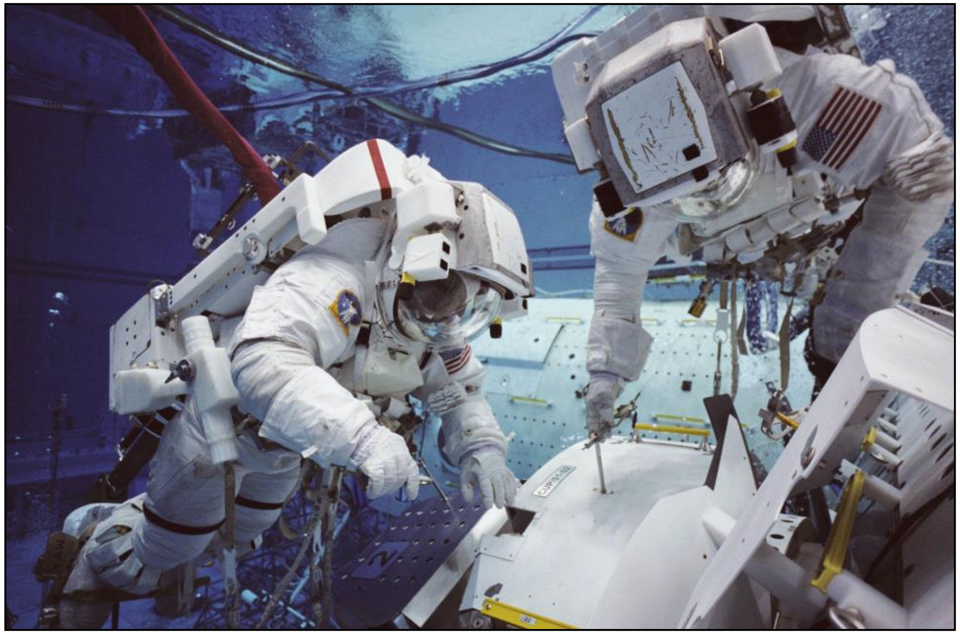
**NASA- Johnson Space Center**

# Comparable Populations?



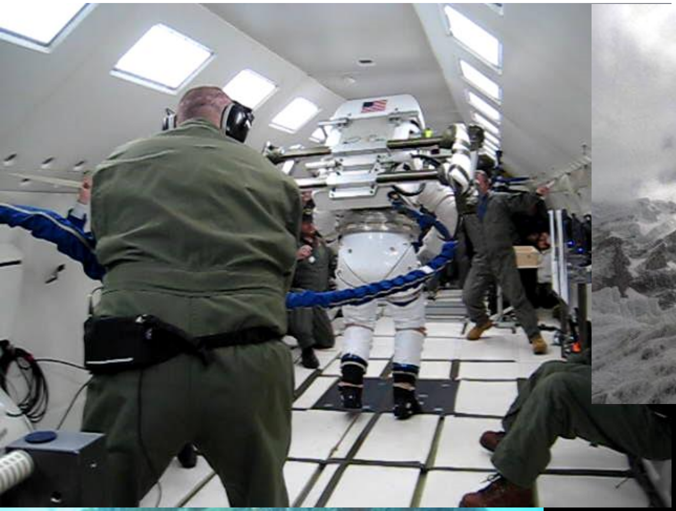
STS-132 EVA NBL training, March, 2010


Mark Buerhle, 23-Jul-2009

# Background

- **Unique aspects of astronaut training for space missions**
- **Musculoskeletal changes in microgravity**
  - Clinical manifestations
- **In-flight countermeasures and post-mission reconditioning**
- **Injuries**
  - Mission phases
    - Pre-flight (training-related injuries)
    - In-flight
    - Post-flight
- **Injury treatment and Prevention Program**

# Training in Unusual Circumstances



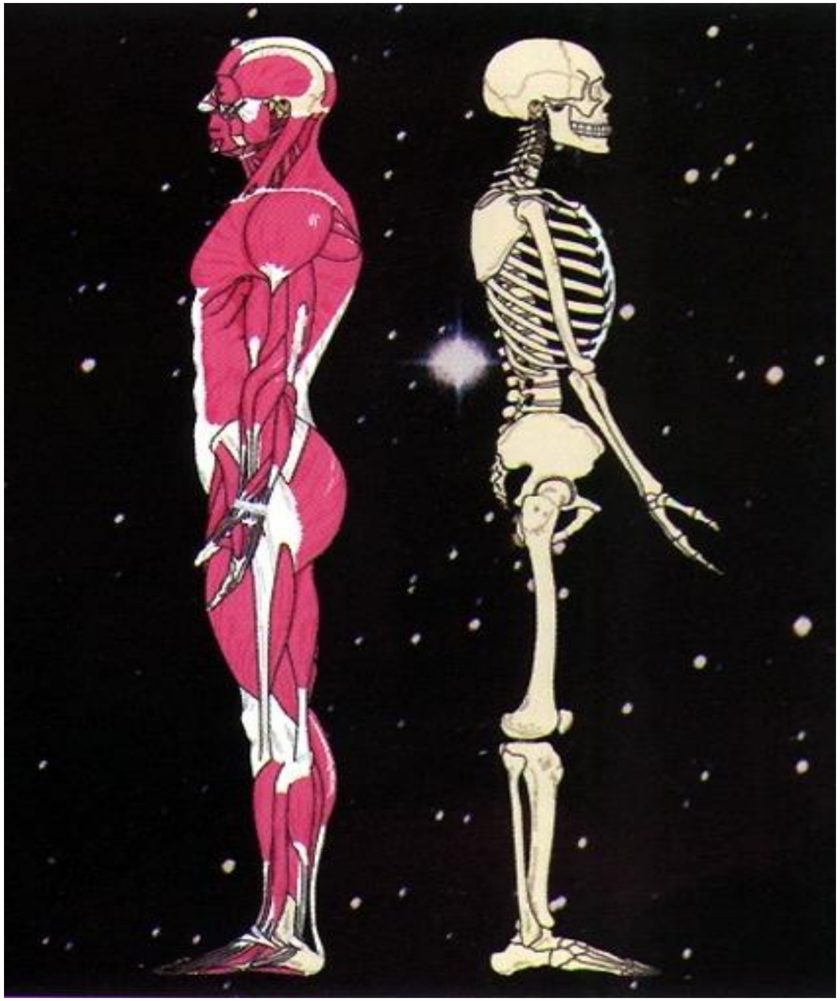






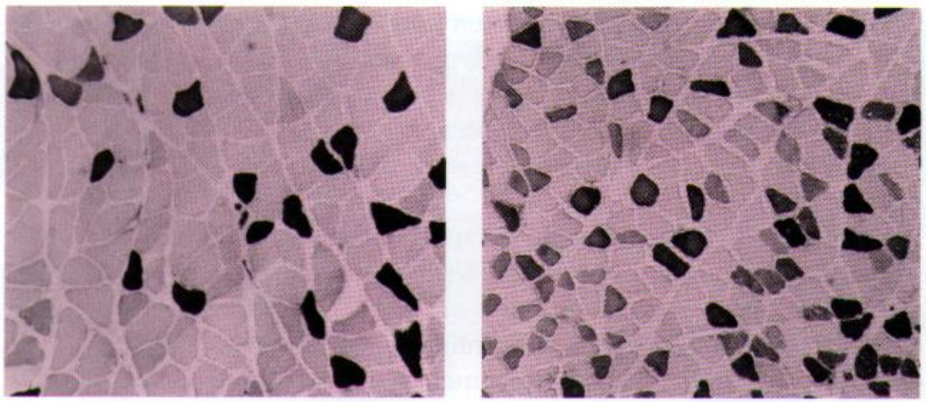


# Muscle and Bone in Space

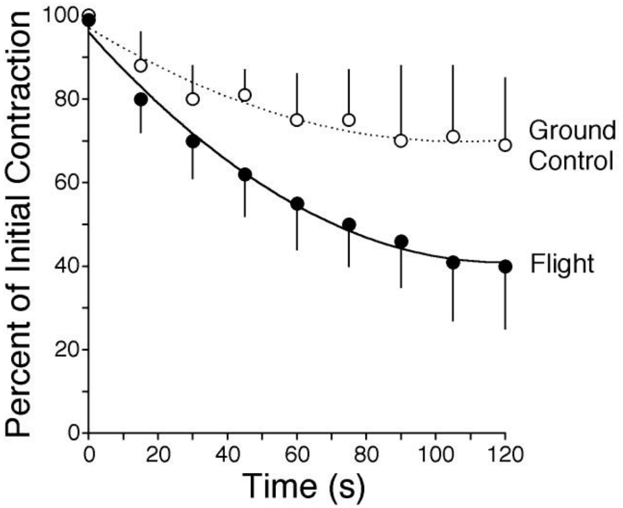


# Effects of Spaceflight on Muscle

- Decrease in body mass
- Decrease in leg volume
- Atrophy of the antigravity muscles (thigh, calf)
  - decrease in leg strength (approx 20-30%)
  - extensor muscles more affected than flexor muscles
- Data in flown rats showed an increase in number of Type II, “fast twitch” muscle fibers (those which are useful for quick body movements but more prone to fatigue)



Ground control Flight



# Muscle/Bone Loss during Spaceflight

- Decrease in weight bearing causes bone demineralization, 1% - 2.4% per month in lower extremities and spine
  - Skeletal changes and loss of total body calcium have been noted in both humans and animals exposed to microgravity from 7 to 237 days.


Nicogossian AE. *Space Physiology and Medicine*, 1989. Lea and Febiger, Philadelphia

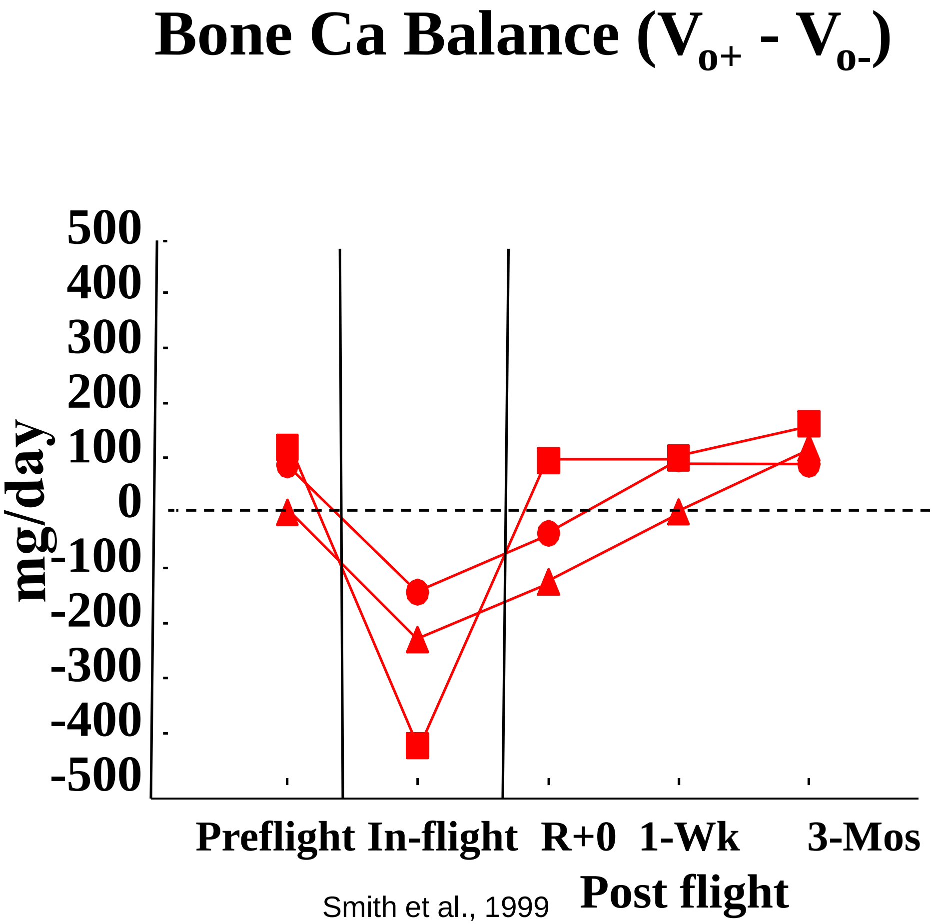
Konieczynski, D. D., Truty, M. J., and Biewener, A. A. *Evaluation of a bone's in vivo 24-hour loading history for physical exercise compared with background loading.* J Orthop Res 16; 1998, 29-37

Baldwin KM, Herrick RE, McCue SA (1993). *Substrate oxidation capacity in rodent skeletal muscle: effects of exposure to zero gravity*. J. Appl. Physiol. 75(6): 2466-2470

# Perturbations in bone remodeling result in osteoporosis

| Risk Factor | Bone Formation | Bone Resorption |
|---|---|---|
| Spaceflight* ("Skeletal unloading") | – ↓ | ↑ |
| **Aging** | ↓ | – |
| Glucocorticoids | ↓ | ↑ |
| Estrogen Deficiency<br>(**Menopause** is not a disease) | ↑↑ | ↑↑↑ |
| Alcohol | ↓ | – |
| Metabolic diseases of High Bone Turnover | ↑↑ | ↑↑ |

# Bone Health assessments

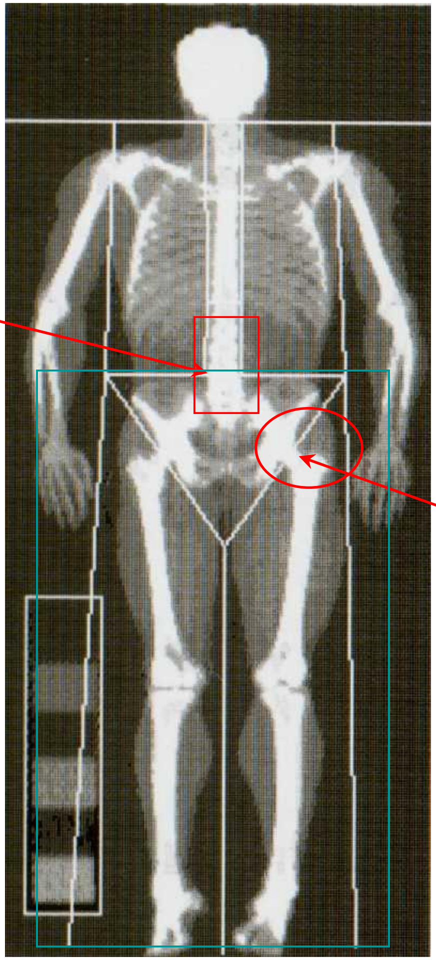



Smith et al., 1999

| | |
|---|---|
| Bone Ca Loss | ~ 250 mg/d |
| Bone Ca Gain | ~ 100 mg/d |
| Recovery: 2-3 x mission | |

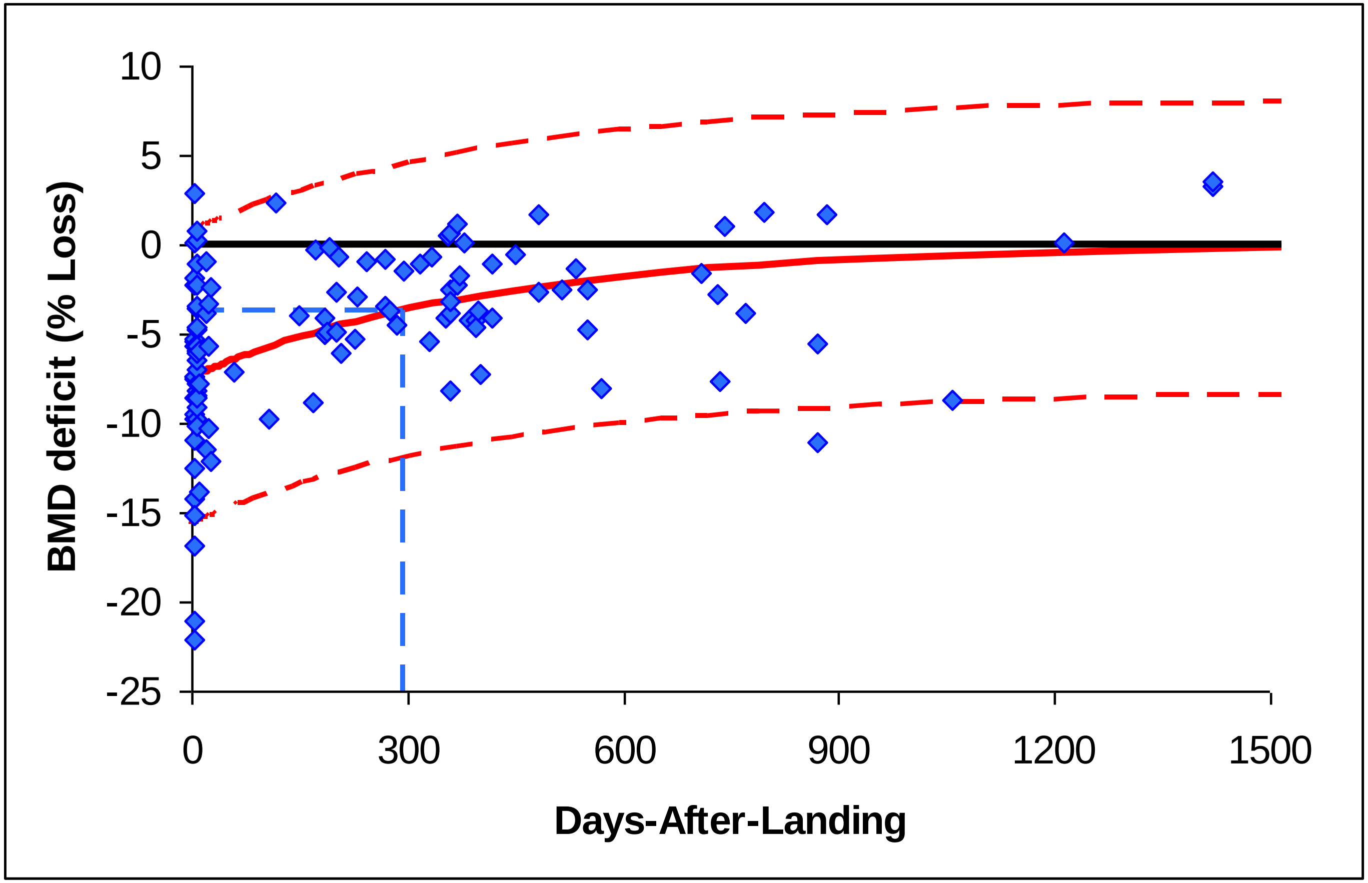
# DXA: BMD losses are specific to weight-bearing bones*, rapid, not necessarily linear.

| **Areal BMD g/cm2** | **%/Month Change ± SD** |
|---|---|
| Lumbar Spine | -1.06±0.63* |
| Femoral Neck | -1.15±0.84* |
| Trochanter | -1.56±0.99* |
| Total Body | -0.35±0.25* |
| Pelvis | -1.35±0.54* |
| Arm | -0.04±0.88 |
| Leg | -0.34±0.33* |
| | |
| *p<0.01, n=16-18 | **LeBlanc et al, 2000** |



# Recovery of BMD with return to gravity

$L_t = L_0 * \exp^{\ln(0.5)*t/HL}$




Trochanter BMD of ISS & Mir Crewmembers
Loss0=7.4% Recovery Half-life=276 d

# Musculoskeletal Changes

## Clinical manifestations

### Acute

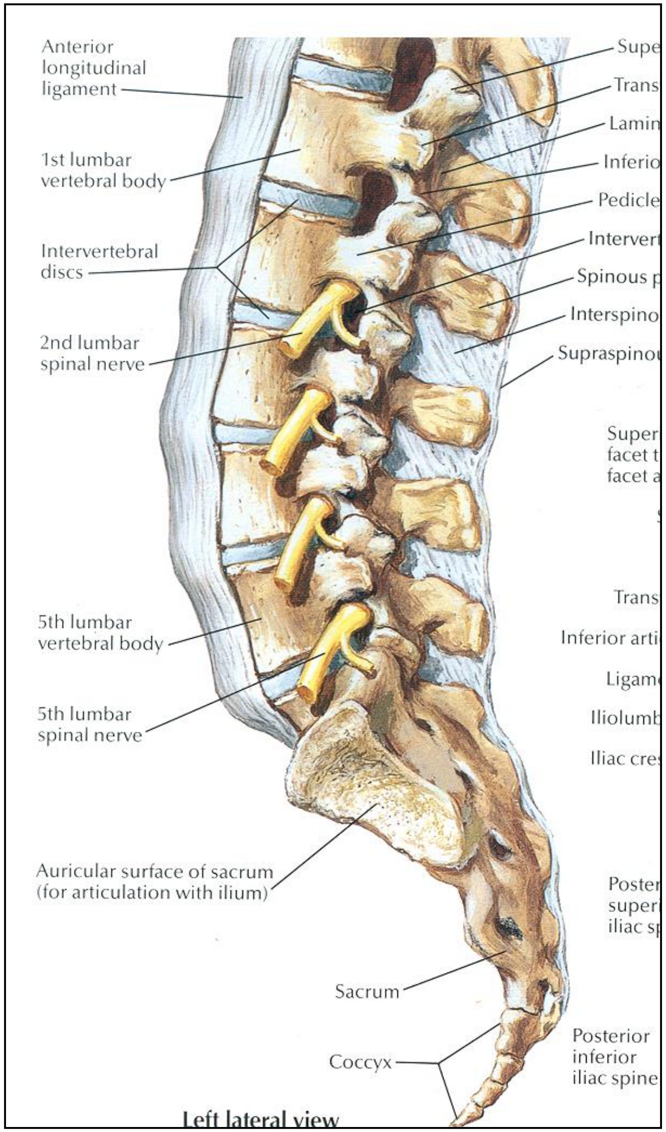
- Symptoms-
  - Back pain (53-68% incidence on orbit to some degree)

    Kertsman EL, **Scheuring RA**, Barnes MG, Dekorse TB, Saile LG. *Space Adaptation Back Pain: A Retrospective Study*. Aviat Space Environ Med. In press, 2010

    Sayson JV, Hargens AR. *Pathophysiology of Low Back Pain during Exposure to Microgravity*. Aviat Space Environ Med 2008 April; 79 (2): 365-73.

    Wing PC, Tsang IK, Susak L, et al. *Back pain and spinal changes in microgravity*. Orthop Clin North Am 1991; 22: 255-62
  - Fatigue (less flexibility and endurance)

# Musculoskeletal Changes



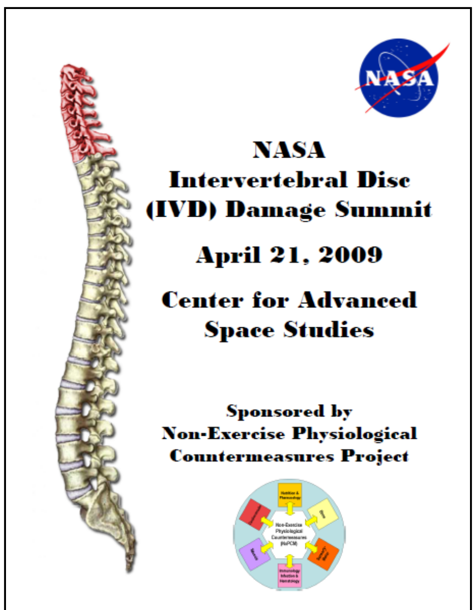

## Back Pain

- Postural change with stretching of tendons and ligaments.
  - Increase in on-orbit height by 2-6 cm
- Etiology?
  - IVD/VEP changes
  - Thoracolumbar myofascial changes
  - Facet
  - Anterior longitudinal ligament
  - Cranio-sacral alterations

# Musculoskeletal Changes

“Chronic” changes

- Tendinosis/tendonopathies
    - Knee, Achilles, elbow
- Intervertebral disc changes and HNP


NASA
Intervertebral Disc
(IVD) Damage Summit

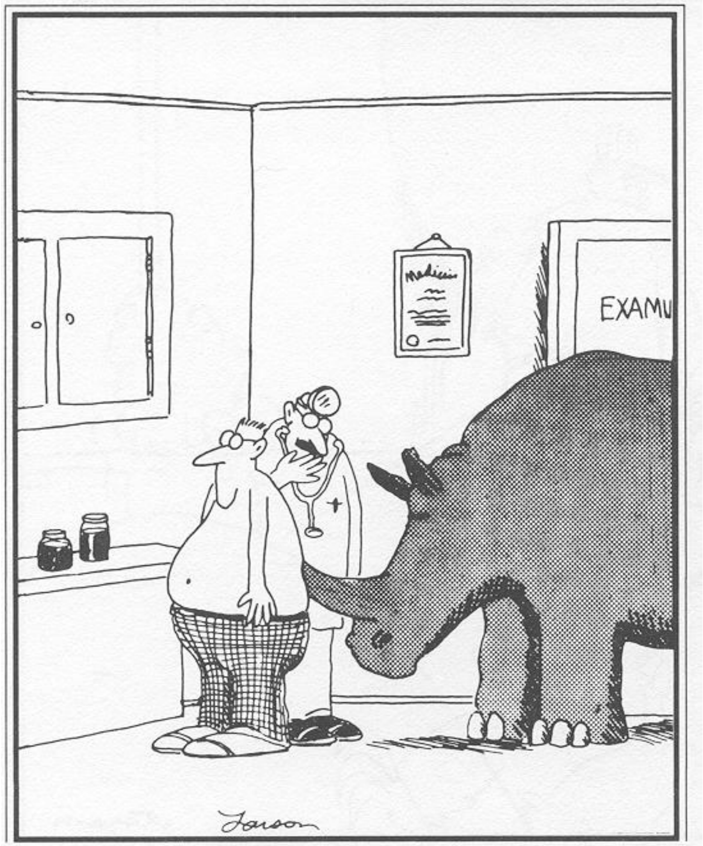
April 21, 2009

Center for Advanced
Space Studies

Sponsored by
Non-Exercise Physiological
Countermeasures Project

# Effects of Long duration space flight on calcium metabolism

- Kidney Stones
- Possible planetary surface operations or post-flight fractures



"Wait a minute here, Mr. Crumbley . . . Maybe it isn't kidney stones after all."

# Musculoskeletal System Loss and Potential Complications/ Countermeasures

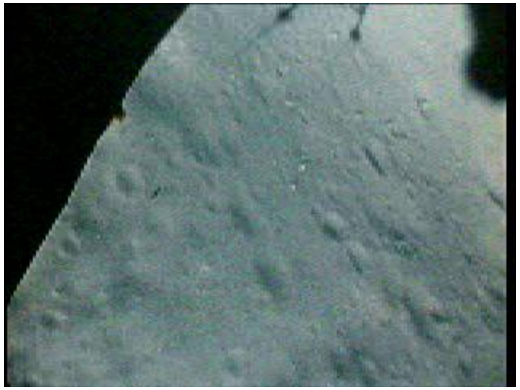
- **Countermeasures in Practice**
  - **For Muscular strength and endurance preservation**
    1) Aerobic (TVIS, CEVIS) and resistive exercise (ARED)
    2) Nutritional supplements
  - **For Reduced bone strength/ Increased Injury or Fracture Risk**:
    1) Resistive exercise hardware (ARED)
    2) Pharmacologic- e.g. High dose Vitamin D, Bisphosphonates
  - **For Urinary Calcium Excretion- Risk of Calculi**
    1) Increased Fluid Intake (2-3L/day)
    2) Pharmacologic- e.g. inhibitor $K^+$ Citrate or $K^+Mg^+$ Citrate
    3) Contingency Management Strategy
- **Countermeasures under consideration/ preparation**
    1) Artificial gravity in transit
    2) PTH, Peptides

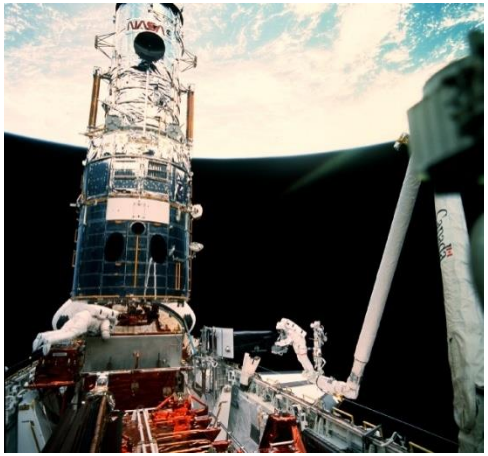
# Exercise Program Objectives

- **Minimize adverse health outcomes associated with spaceflight**
- **Guarantee effective in-flight performance and safety**
- **Provide a functional return to a terrestrial environment**
- **Promote an optimal rate of post-flight recovery**
- **Minimize lifetime health risks**

# Potential Operational Implications of Reduced Muscle Strength and Endurance

- Landing proficiency
- Egress capability
- IVA/EVA work capacity

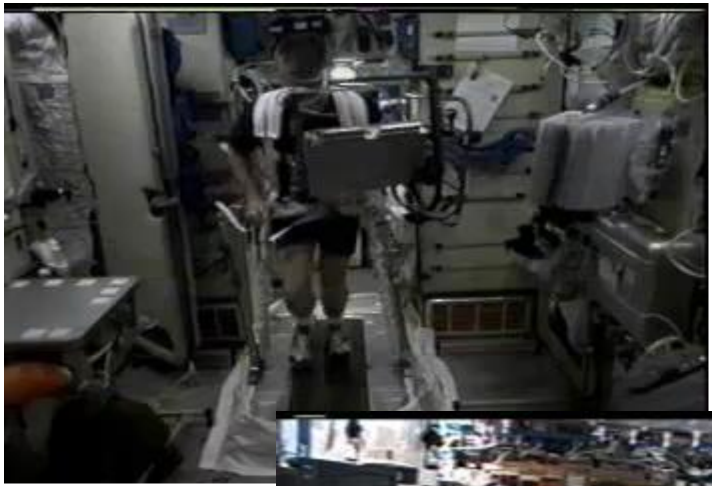




NASA EPDC 2016

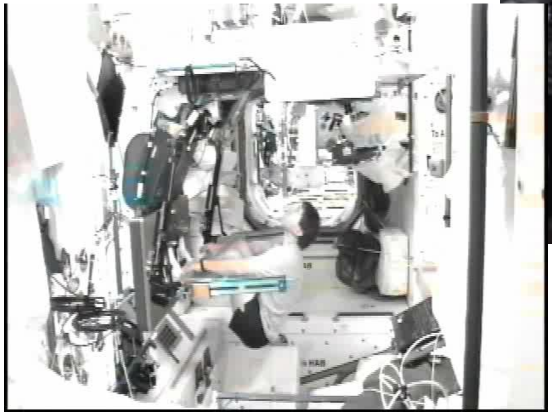
# Exercise Countermeasures: In-Flight

- T2: Treadmill
  - Neurovestibular
  - Cardiovascular
  - Musculoskeletal
- CEVIS: Cycle Ergometer
  - Cardiovascular
- Advanced Resistive Exercise Device: ARED
  - Musculoskeletal

TVIS



CEVIS



ARED

# Countermeasures *cont'd…*

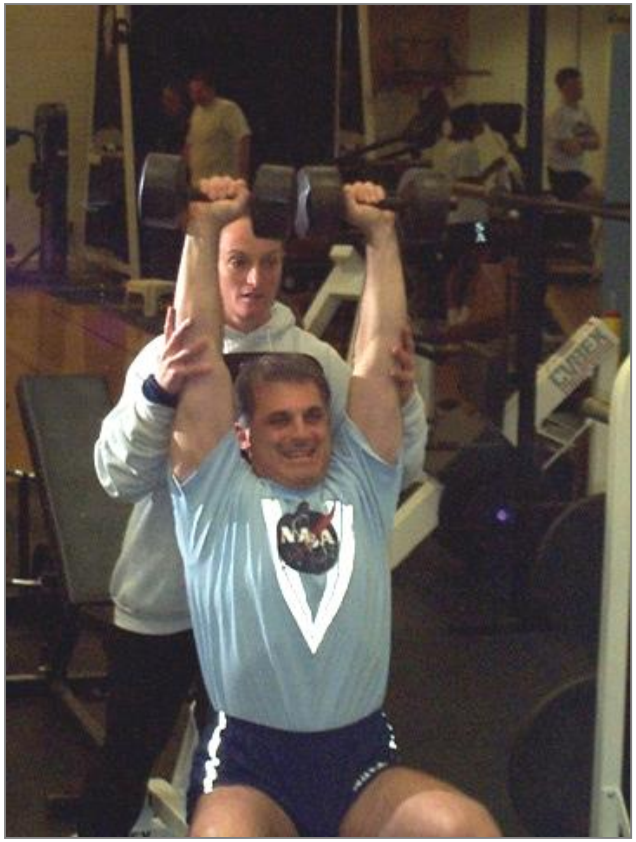
- Other exercise options
  - Traction on "bungee cords"
  - Historically the "Exer-Genie" was used during the Apollo missions

*Photos NASA*

# In-flight ISS Exercise Plan
# 2.5 hrs/d; 6d/wk

- **Treadmill**
  - Intensity: 60% to 85% $HR_{max}$(continuous and interval training)
  - Duration: 30 min
  - Frequency: 2 to 6x/wk -↑ frequency the last month of flight
- **Cycle**
  - Intensity: 60% to 80% $HR_{max}$ (continuous and interval training)
  - Duration: 30 min
  - Frequency: 3 to 4x/wk
- **Resistance Exercise**
  - Intensity: Varies per crewmember and exercise
  - Frequency:
    - 2x/wk upper body exercise (curls, presses)
    - 2 to 3x/wk lower body exercise (squats, heel raises, dead lifts)

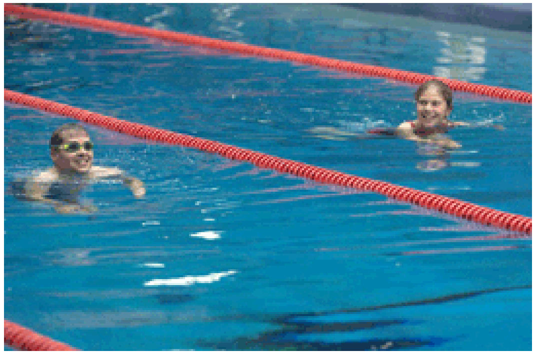
# Post-flight Reconditioning



### Objective
- To optimize rate of recovery
- To reduce incidence of injury

### Description
- Massage
- Flexibility
- Progressive resistance exercises
- Cardiovascular conditioning

### Schedule
- 2 hours daily
- R+0 through R+45



# Post-flight reconditioning *cont'd…*

- Dynamic stretching and warm-up: R+0d
- Mobialanception: R+0d
- Medicine ball: R+0d
- Ladder and cone drills: R+7d
- Jumping drills: R+21d
- Core exercises: R+1d
- Static stretching: R+0d

# Musculoskeletal Injuries

## ♦ Known

- US Astronauts suffer musculoskeletal injuries during **pre-flight** and **post-flight** phases

Jennings RT, Bagian JP. *Musculoskeletal injury review in the US space program*. Aviat Space Environ Med 1996, 67(8): 762-766.

Viegas SF, Williams D, Jones J, Strauss S, Clark J. *Physical demands and injuries to the upper extremity associated with the space program*. J Hand Surg 2004, 29A(3): 359-366.

- A review of astronaut injuries published in the longitudinal study of astronaut health (LSAH) for shuttle astronauts between STS-1 and STS-89 revealed a greater *in-flight* injury rate among crewmembers than their age and sex-matched cohorts

Wear M. *Injury rate of shuttle astronauts*. The Longitudinal Study of Astronaut Health Newsletter, December 1999, 8(2): 1,4

## ♦ Unknown

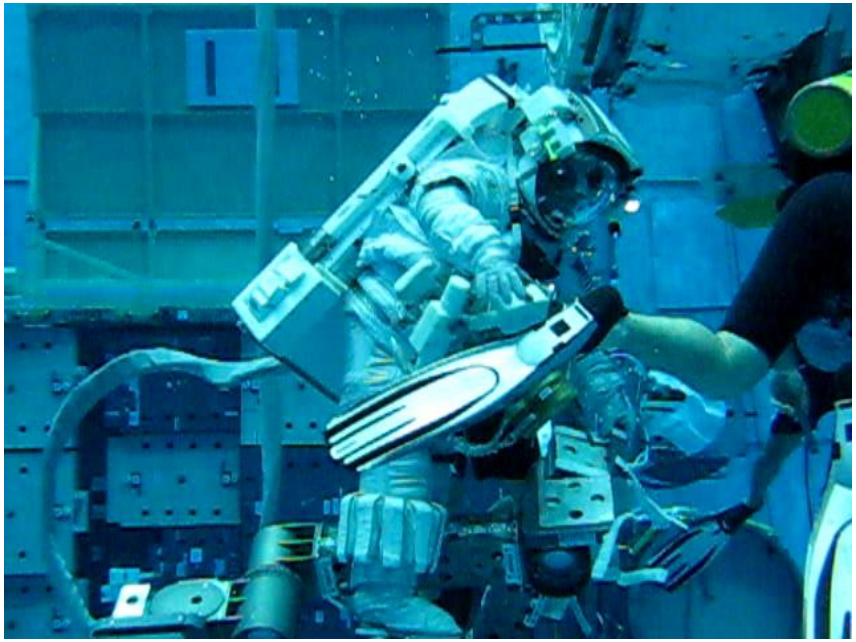
- The incidence of **in-flight** injuries for astronauts in the US space program across all programs
  - How much of the increase noted in the LSAH study was attributed to pre-flight training, post-flight injury due to deconditioning, or in-flight injury as a result of mission activities?

# EVA Suit Trauma

- **Existing Space Suits cause significant trauma to crew members**
  - Oncholysis-Finger nail damage
  - Shoulder and other orthopedic injuries
  - Bruising, abrasions, parathesias
- **Potential causes**
  - Restricted scapulo-thoracic movement and p within suit
  - Altered suit kinematics resulting human biom consider

# Pre-flight Training-Related Injuries

- **Shoulder**
  - Rotator cuff injuries
  - SLAP lesions
- **Elbow**
  - Lateral epicondylitis
- **Finger**
  - Fingernail delamination



# Shoulder Injuries


# In-Flight Medical Conditions Incidence Comparisons (events/person-year)

- **Sleep Disturbance: 3.80**
- **Sprain/Strain/Contusion: 3.34**
- **Skin rash: 3.29**
- **Skin abrasion/laceration: 3.11**
- **Eye foreign body abrasion: 2.60**
- **Cough (URI): 1.35**
- **UTI (females): 1.29**
- **Diarrhea: 1.21**

RESEARCH ARTICLE

## Musculoskeletal Injuries and Minor Trauma in Space: Incidence and Injury Mechanisms in U.S. Astronauts

Richard A. Scheuring, Charles H. Mathers, Jeffrey A. Jones, and Mary L. Wear

Scheuring RA, Mathers CH, Jones JA, wear ML. *Musculoskeletal injuries and minor trauma in space: incidence and injury mechanisms in U.S. astronauts*. Aviat Space Environ Med 2009; 80:117–24.

***Introduction:*** Astronauts have sustained musculoskeletal injuries and minor trauma in space, but our knowledge of these injuries is based mainly on anecdotal reports. The purpose of our study was to catalog and analyze all in-flight musculoskeletal injuries occurring throughout the U.S. space program to date. ***Methods:*** A database on in-flight musculoskeletal injuries among U.S. astronauts was generated from records at the Johnson Space Center. ***Results:*** A total of 219 in-flight musculoskeletal injuries were identified, 198 occurring in men and 21 in women. Incidence over the course of the space program was 0.021 per flight day for men and 0.015 for women. Hand injuries represented the most common location of injuries, with abrasions and small lacerations representing common manifestations of these injuries. Crew activity in the spacecraft cabin such as translating between modules, aerobic and resistive exercise, and injuries caused by the extravehicular activity (EVA) suit components were the leading causes of musculoskeletal injuries. Exercise-related injuries accounted for an incidence of 0.003 per day and exercise is the most frequent source of injuries in astronauts living aboard the International Space Station (ISS). Interaction with EVA suit components accounted for an incidence of 0.26 injuries per EVA. ***Discussion:*** Hand injuries were among the most common events occurring in U.S. astronauts during spaceflight. Identifying the incidence and mechanism of in-flight injuries will allow flight surgeons to quantify the amount of medical supplies needed in the design of next-generation spacecraft. Engineers can use in-flight injury data to further refine the EVA suit and vehicle components.

**Keywords:** astronaut, NASA, strain, sprain, abrasion, contusion, laceration, dislocation, EVA, injury.

NASA ASTRONAUTS face a variety of occupational hazards throughout their career. In addition to the risks inherent to space travel, astronauts perform physically demanding tasks in unfamiliar environments. Coupled with bone and muscle mass loss due to the effects of microgravity on the human body, one could hypothesize that astronauts may be at increased risk for sustaining musculoskeletal injuries while conducting space operations. Indeed, anecdotal reports from astronauts and postflight mission debriefings in all NASA spaceflight programs support this theory, as many astronauts have noted in-flight musculoskeletal injuries. However, until recently, our understanding of these injuries was based primarily on anecdotal reports, without evidence-based data to support these claims.

Jennings and Bagian conducted a study examining the terrestrial-based orthopedic injury history of astronauts during the period of 1987 to 1995 (5). The authors found astronauts sustained numerous fractures, serious ligament, cartilage, or soft tissue injuries, resulting in 28 orthopedic surgical procedures during this period. Knee injuries accounted for 19 of the surgical interventions, while running, skiing, and basketball were the activities most frequently associated with injuries. The authors recommended the hiring of full-time personal trainers and the designation of a facility for training purposes at Johnson Space Center, both of which are now in place as manifested in the Astronaut Strength, Conditioning, and Rehabilitation (ASCR) program. Jennings and Bagian recognized the importance of understanding the mechanism of injury or trauma, noting that it was "time to move beyond documentation of injuries and treatment to providing a program that strives to prevent or mitigate training-related injuries." This important study is often cited in discussions regarding musculoskeletal injuries and prevention in astronauts, but did not address in-flight occurrences.

An article printed in the Longitudinal Study of Astronaut Health (LSAH) newsletter in December 1999 examined the musculoskeletal injury rates of shuttle astronauts between Shuttle Transport System (STS)-1 and STS-89 (12). The authors found an overall greater in-flight injury rate among astronauts than comparison participants in the LSAH. Interestingly, they also found a threefold higher injury rate within astronauts' mission period, defined as 1 yr preflight to 1 yr postflight, versus the rate outside the mission period. This raised questions as to how much of this increase was attributed to preflight training, postflight injury due to de-conditioning, or in-flight injury.

We know that astronauts sustain injuries during the preflight period, especially during training sessions in

From NASA Johnson Space Center, Houston, TX; The University of Texas Medical Branch, Galveston, TX; and Wyle Laboratories, Houston, TX.

This manuscript was received for review in January 2008. It was accepted for publication in November 2008.

Address reprint requests to: Richard A. Scheuring, D.O., M.S., NASA Johnson Space Center, SD4, 2101 NASA Parkway, Houston, TX 77058; richard.a.scheuring@nasa.gov.



DOI: 10.3357/ASEM.2270.2009

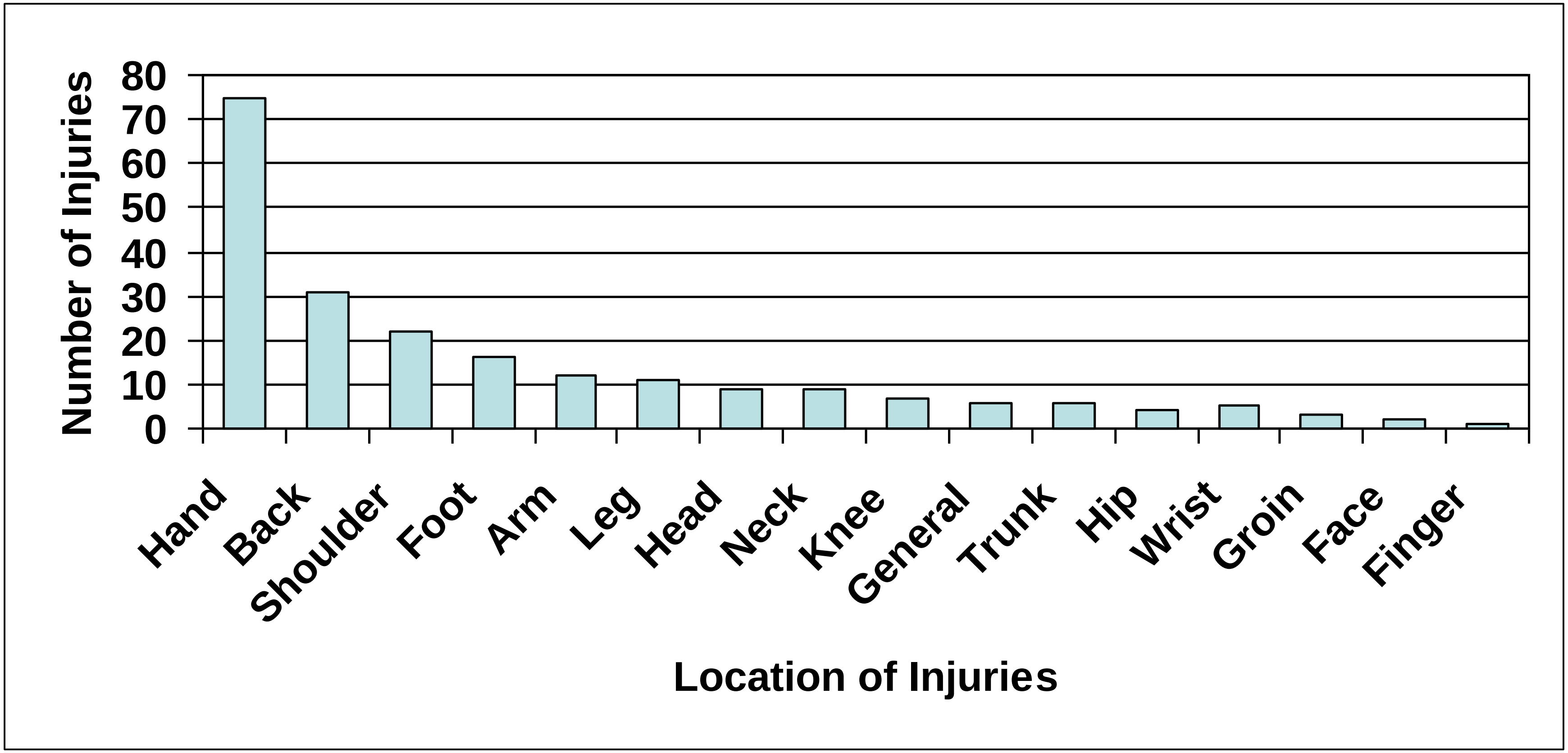
# Methods

- **To examine in-flight musculoskeletal injuries and minor trauma, our results included:**
  - Abrasions
  - Contusions
  - Lacerations
  - Sprains
  - Strains
  - Dislocations.

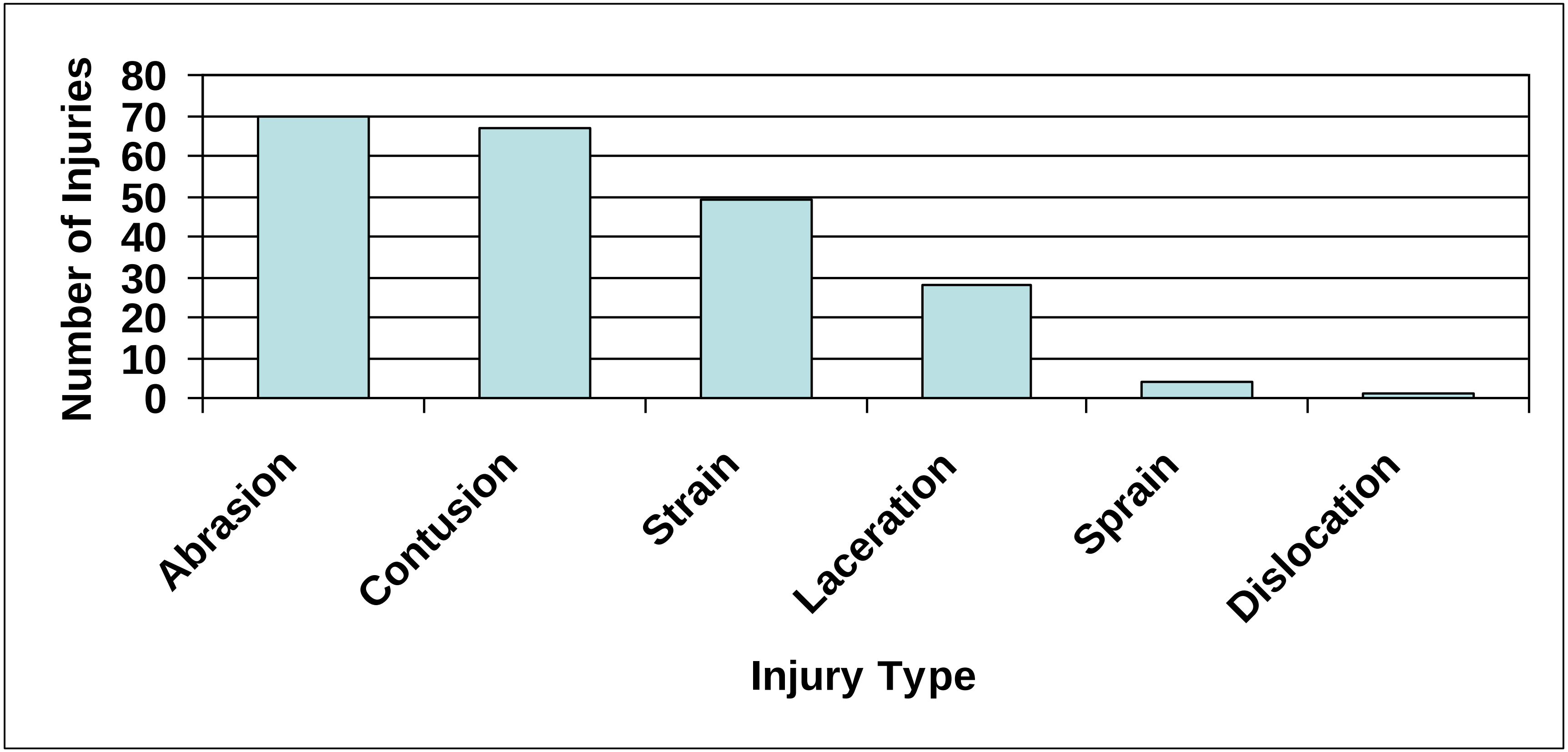
# Results

- A total of 369 in-flight musculoskeletal conditions were found, from which 219 in-flight musculoskeletal injuries were identified
  - 21 in women and 198 in men.
  - Incidence over the course of the space program was 0.021 per flight day for men and 0.015 for women.
  - Hand injuries represented the most common location of injuries throughout the U.S. space program, with abrasions and small lacerations representing common manifestations of these injuries.
  - Exercise-related injuries accounted for an incidence rate of 0.003 per day.

# Results


Number of Injuries
80
70
60
50
40
30
20
10
0
Hand
Back
Shoulder
Foot
Arm
Leg
Head
Neck
Knee
General
Trunk
Hip
Wrist
Groin
Face
Finger
Location of Injuries

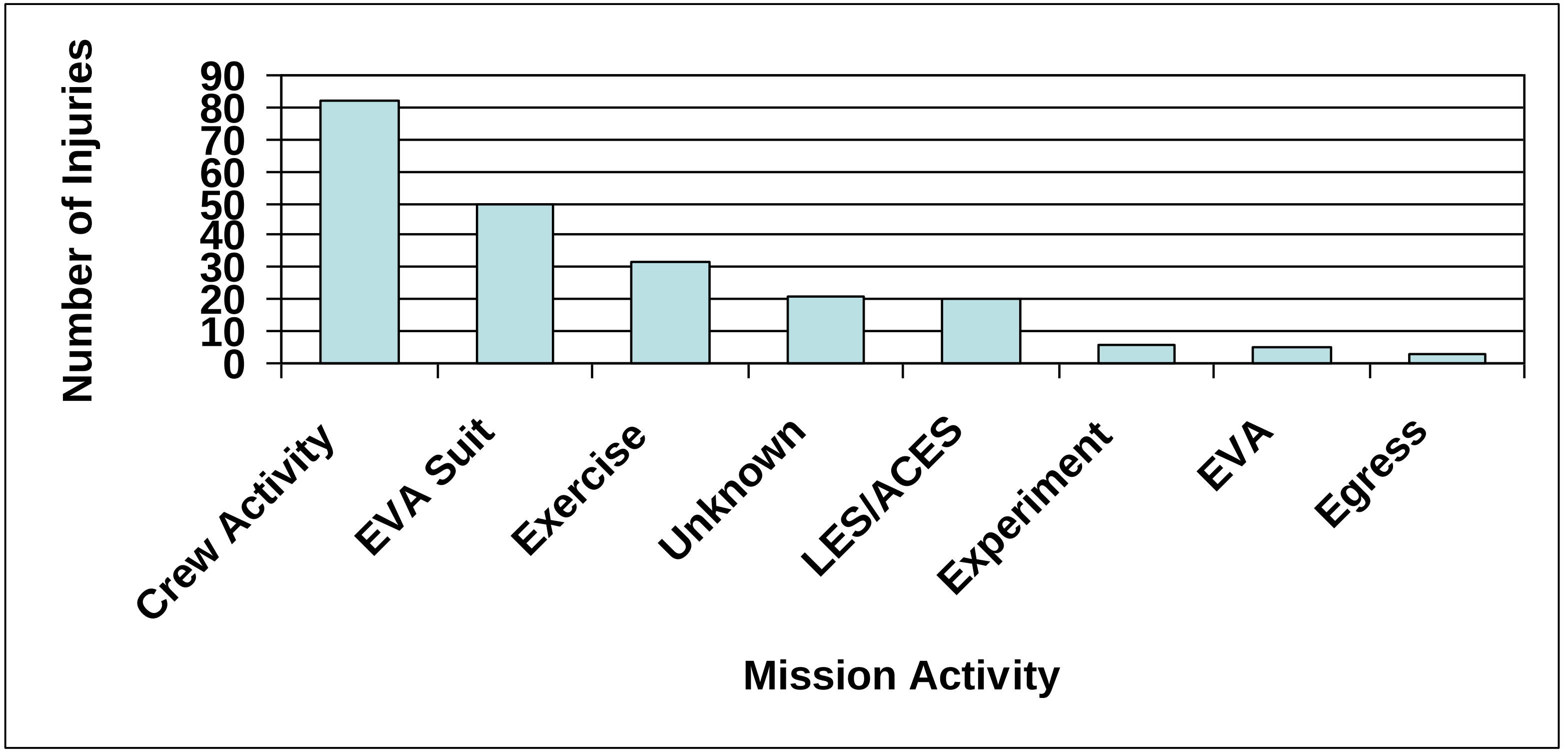
# Results



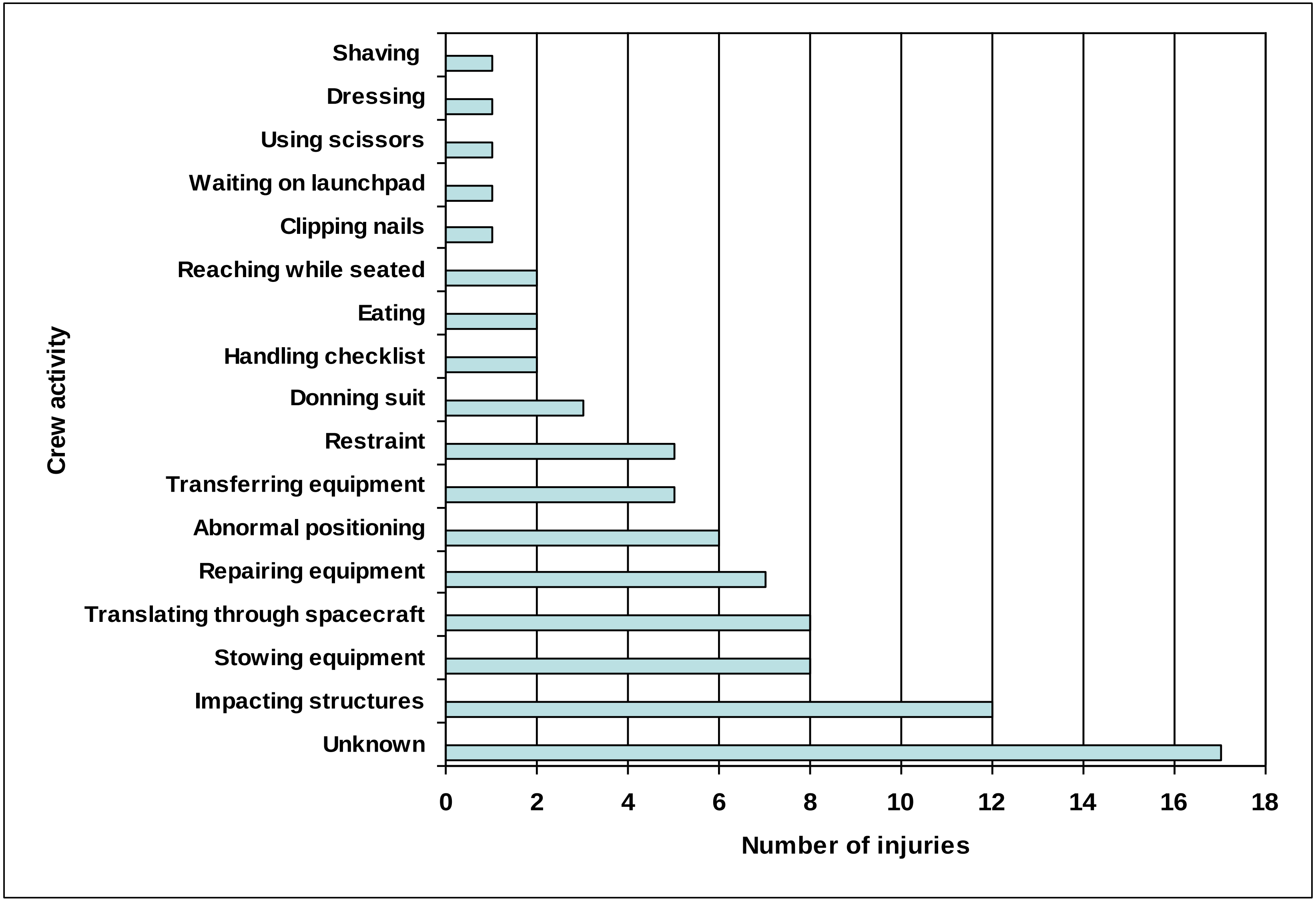
Number of Injuries
80
70
60
50
40
30
20
10
0
Abrasion
Contusion
Strain
Laceration
Sprain
Dislocation
Injury Type

# Results

- Crew activity in the spacecraft cabin such as translating between modules, exercise, and injuries caused by the extravehicular activity (EVA) suit components were the leading causes of musculoskeletal injuries throughout the space program.



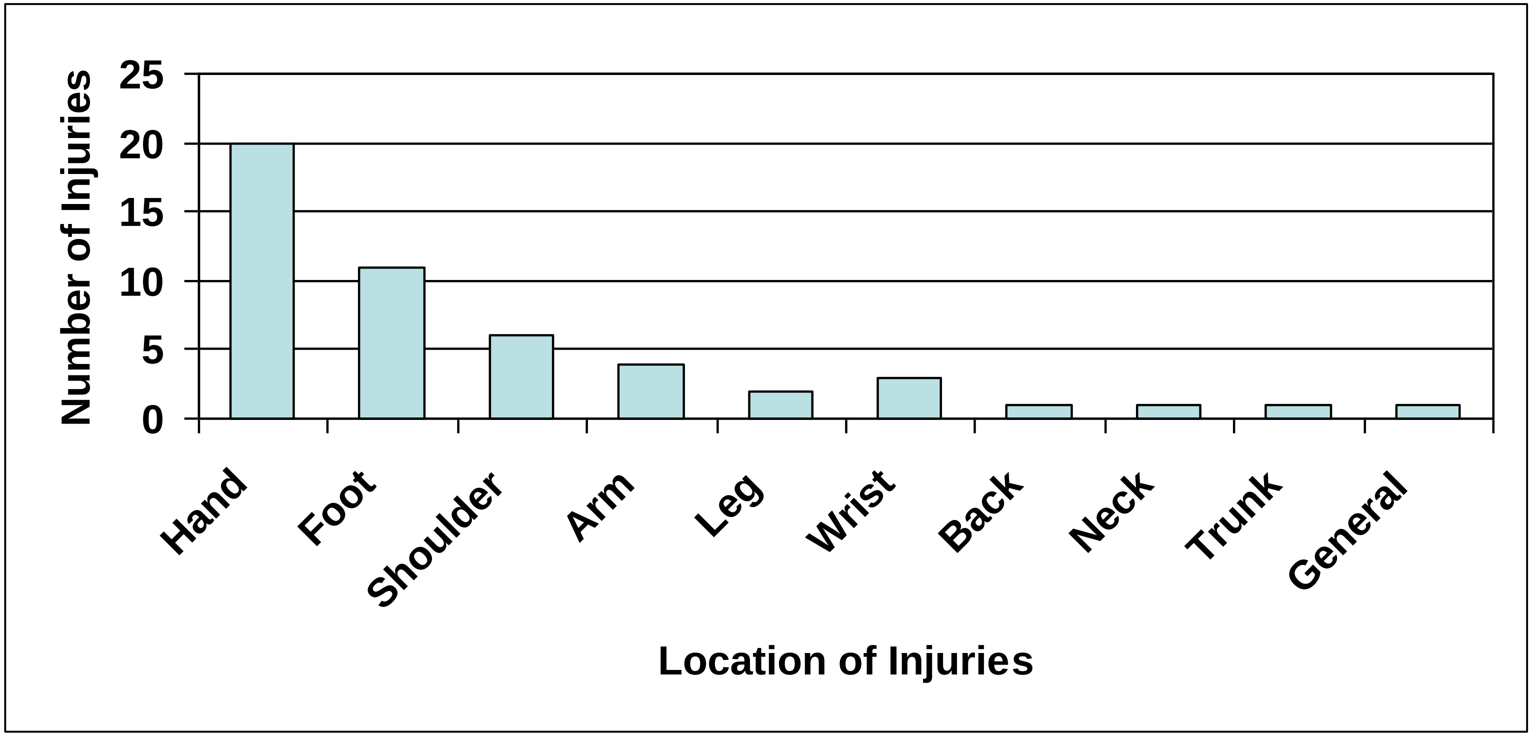
# Results



Shaving
Dressing
Using scissors
Waiting on launchpad
Clipping nails
Reaching while seated
Eating
Handling checklist
Donning suit
Restraint
Transferring equipment
Abnormal positioning
Repairing equipment
Translating through spacecraft
Stowing equipment
Impacting structures
Unknown
Crew activity
0
2
4
6
8
10
12
14
16
18
Number of injuries

# Results

- The EVA injuries incidence from all sources was 0.05 per hour in 1087.8 hours of EVA activity during the space program to date. This equates to a per day incidence of 1.21 in-flight musculoskeletal injuries.



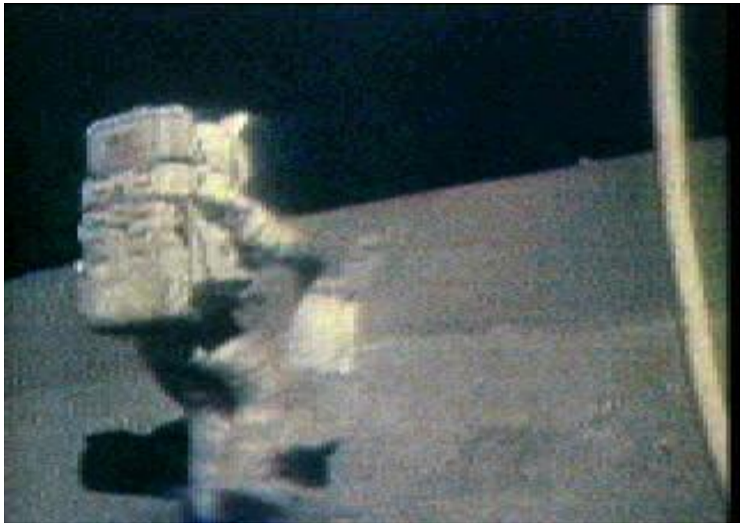
# Results

Photo courtesy of Drs. Sam Strauss and Jeff Jones, NASA-JSC

Photo courtesy of Dr. Joseph Dervay, NASA-JSC

- **EVA accounted for an incidence rate of 0.26 injuries per EVA.**
  - EVA injuries occurred primarily in the hands and feet
  - These injuries may represent an exacerbation of pre-flight injury during training in the Neutral Buoyancy Laboratory

# Results



## Apollo Lunar Surface Musculoskeletal Events or Minor Trauma

- 9 Events were reported on the lunar surface related to EVA
  - 5 events located in the hand
  - Muscle fatigue during lunar EVA related to activities in the glove (unscrewing core tubes, etc.)
  - Finger soreness attributed to high work load
  - MCP, distal phalanx pain, swelling and abrasions after lunar 3/3 EVA
    - "*Completing a subsequent EVA would have been very difficult on account of how sore and swollen my hands were*"
- 2 events occurred in the wrist
  - Wrist laceration due to suit wrist ring cutting into skin
  - Wrist soreness where suit sleeve repetitively rubbed on surface
- 1 event resulted in shoulder strain after EVA 2/3
  - Crewmember injured shoulder during surface drilling activity
    - Required large doses of aspirin to relieve pain
- 1 event described as general muscle fatigue while covering large distances by foot on the lunar surface

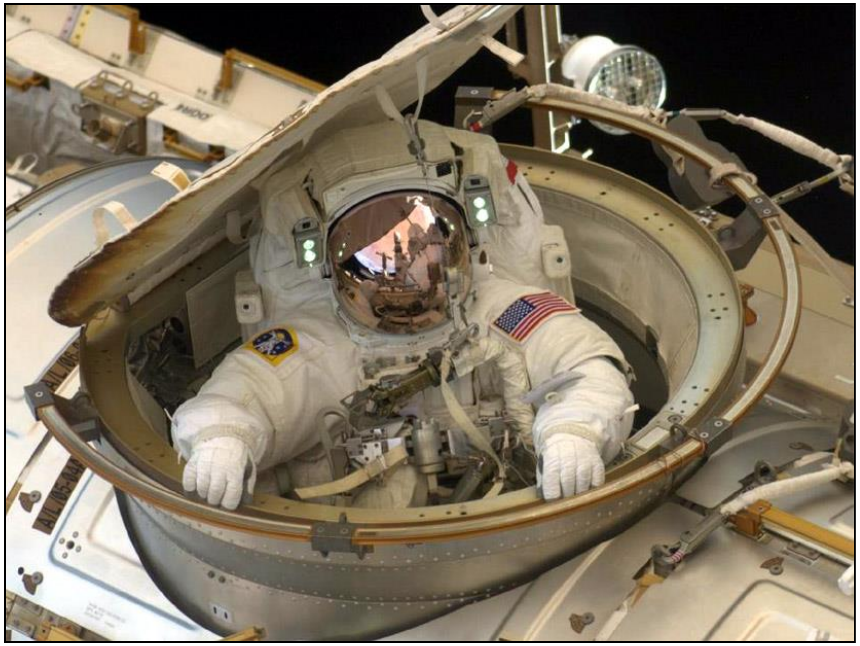
**Scheuring RA**, Davis, JR, et. al. *The Apollo Medical Operations Project: Recommendations to Improve Crew Health and Performance for Future Exploration Missions and Lunar Surface Operations*. Acta Astronautica, 63 (2008); 980 – 987.

# Post-flight Injuries

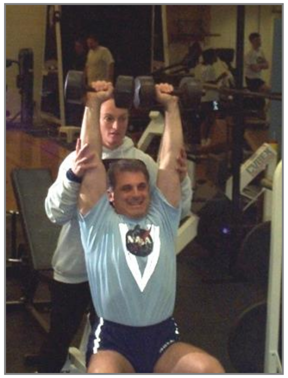


# Risk Factors for Shoulder Injury during ISS EVA

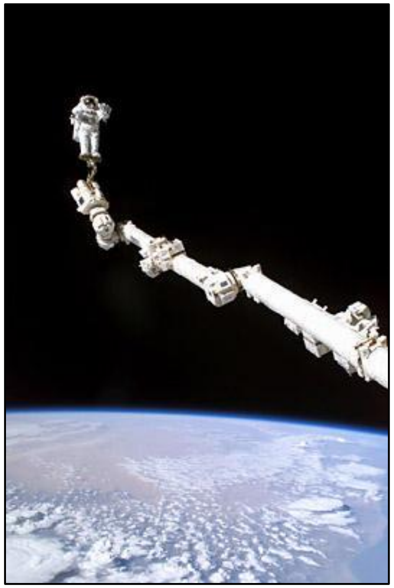
- Don-doffing
- Airlock ingress/egress
- Overhead tasks

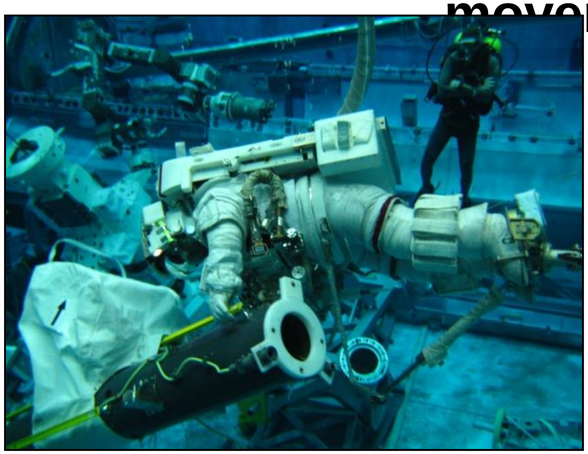


# EVA Fitness Program



- **A well rounded exercise plan allows the crew to attain greater overall strength through functional movement patterns**
- **Prescribe multiple joint/multiple muscle exercise movements**





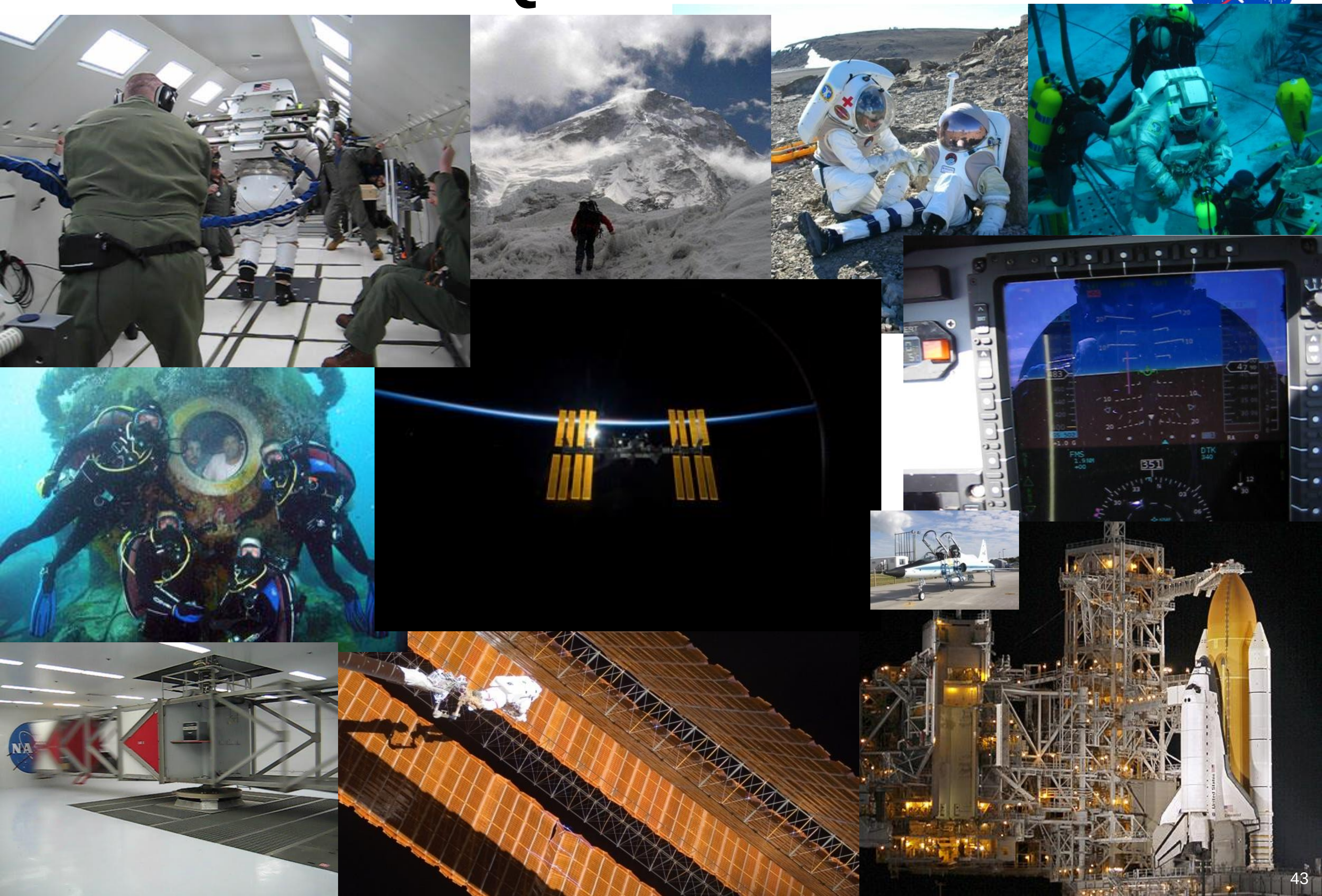
# EVA Fitness Program

- **Triple Extension & Lower Extremity Based Exercises – Squats, Deadlifts, RDL’s, Hamstring Curls, Kettlebell Swings, etc.**
- **Pushing Exercises – Bench Press, Shoulder Press, Push-Ups, etc.**
- **Pulling Exercise – Cable Row, Lat Pulldown, Pull-Ups, etc.**
- **Accessory Exercises – Shoulder Rotator Cuff Maintenance Program, Wrist/Forearm Exercises**

# Acknowledgements


- Jean Sibonga, PhD- NASA Bone & Muscle Physiology Lab
- Lori Putz-Synder, PhD- NASA Exercise Physiology Lab
- Jim Loehr, MS- NASA Astronaut Strength, Conditioning and Rehabilitation (ASCRs)
- Greg Shaskan, MD- UTMB/Wyle Laboratories

# Questions?



# Back Up slides

# QCT After Flight: Greater percentage loss vBMD in trabecular bone compartment (n=16 ISS)

***NOT detectable by DXA**

| Index DXA | %/Month Change ± SD | Index QCT | %/Month Change ± SD |
|---|---|---|---|
| **aBMD Lumbar Spine** | **1.06±0.63*** | **Integral vBMD Lumbar Spine** | **0.9±0.5** |
| | | ***Trabecular vBMD Lumbar Spine** | **0.7±0.6** |
| **aBMD Femoral Neck** | **1.15±0.84*** | **Integral vBMD Femoral Neck** | **1.2±0.7** |
| | | ***Trabecular vBMD Femoral Neck** | **2.7±1.9** |
| **aBMD Trochanter** | **1.56±0.99*** | **Integral vBMD Trochanter** | **1.5+0.9** |
| ***p<0.01, n=16-18** | | ***Trabecular vBMD Trochanter** | **2.2+0.9** |

LeBlanc, J M Neuron Interact, 2000;
Lang , J Bone Miner Res, 2004;
Vico, The Lancet 2000

# Results

## Exercise

- High number of minor back injuries occurred while using the exercise equipment on the International Space Station
  - Treadmill with Vibration and Isolation System (TVIS) was associated with 2 injuries
  - Interim Resistive Exercise Device (IRED) accounted for 7 injuries
  - Use of both devices was blamed for the remaining 3 injuries
- Exercise activity or use of exercise equipment was associated with an injury rate of 0.003 injuries per day

# Discussion

- The real power of the in-flight musculoskeletal database is evident when analyzing specific scenarios leading to these injuries.
  - Crew activity, such as stowing equipment, translating through and impacting structures within the spacecraft cabin caused most of the injuries in-flight
    - **This might be of interest to space vehicle design engineers as the interiors of spacecraft such as Skylab and ISS allow for more freedom of movement.**
  - EVA places astronauts in situations of high physical demand, and tests the capability of equipment as it does the men and women performing the activity. We found a relatively large number of injuries that occurred during EVA throughout the space program.

# Discussion

- In our initial search for all musculoskeletal conditions in the space program, we found that many Apollo crewmembers who performed EVA on the moon noted problems with their hands. For example, one astronaut remarked, “EVA 1 was clearly the hardest…particularly in the hands. Our fingers were very sore.” Another commented that his hands were “very sore after each EVA.”
  - **Apollo conducted 2-3 EVA’s for 3-7 hours per EVA**
    - **The Constellation program (CxP) will start out with 7 day lunar missions and progress to 6 month stays over the period of 3-4 years**

# Discussion

- **Limitations**
  - Though the database contains detailed information on mechanism of injury, the post-flight mission debriefs did not always discuss the other parameters examined, such as exercise, treatment, and post-flight outcome. Thus, the database is incomplete as many entries lack information in these areas.
  - Information about musculoskeletal problems was not always elicited from flight crews, and the manner in which it was collected changed over the course of the space program. In addition, certain entries needed refining as to the accuracy of the diagnosis.

# Conclusion

- The in-flight musculoskeletal database provides the foundation for directing operationally-relevant research in space medicine.
  - **This effort will enable medical operations to develop medical kits, training programs, and preventive medicine strategies for future CxP missions**
    - **Quantify medications and medical supplies for next-generation spacecraft**
    - **Objective data for engineers to determine weight requirements**

# Conclusion

- Flight surgeons can make specific recommendations to astronauts based on injury data, such as emphasizing hand protection while in-flight

- EVA and spacecraft engineers can examine evidence-based data on injuries and design countermeasures to help prevent them